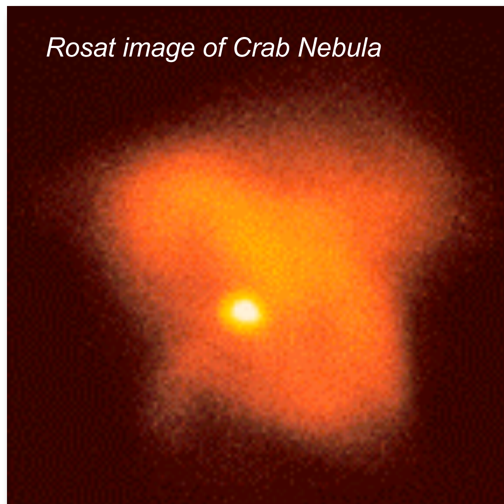
UCRL-PRES-233999

*First NIF Nuclear Astrophysics Workshop*

# High Energy Density S&T at LLNL




Karl van Bibber
Physics & Advanced Technologies Directorate
August 29, 2007

# High Energy Density S&T is the Lab's premier competency & we aspire to be the HEDS center of the world

- It is central to the Lab's primary mission
- It is a broadly distributed competency with multiple stakeholders
  - Primarily DNT, NIF, PAT, supported by CMLS, Eng, Comp
  - Not well-structured yet, but NIF will help provide that structure
- We seek to be second-to-none
  - But integrating with and supporting a national HED program
  - There is a $25M HEDLP joint program (NNSA + SC) in FY08 budget

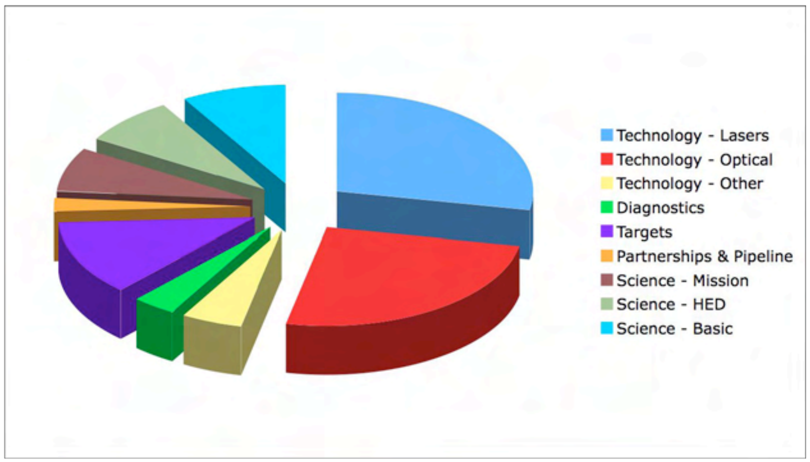
This talk will focus on the Laboratory's HEDS&T portfolio supported by its primary discretionary resource, LDRD

# HED at LLNL is not a Program, but rather an Enterprise!

- We need complete horizontal & vertical integration
  - Mission-driven science
    - Ignition
    - Weapons
    - Basic science (astrophysics, nuclear, materials)
    - Energy
  - Platforms (NIF, JLF)
  - Critical technologies (e.g. lasers, optics, controls, …)
  - Targets
  - Diagnostics
  - Algorithms, computation
  - Damage mitigation campaigns (to boost productivity)
  - Strategic partnerships  (e.g. ILSA)
  - Human capital pipeline (e.g. ILSA)

**We have to own & steward all of these elements**

# Profile of the Lab's HED LDRD investments



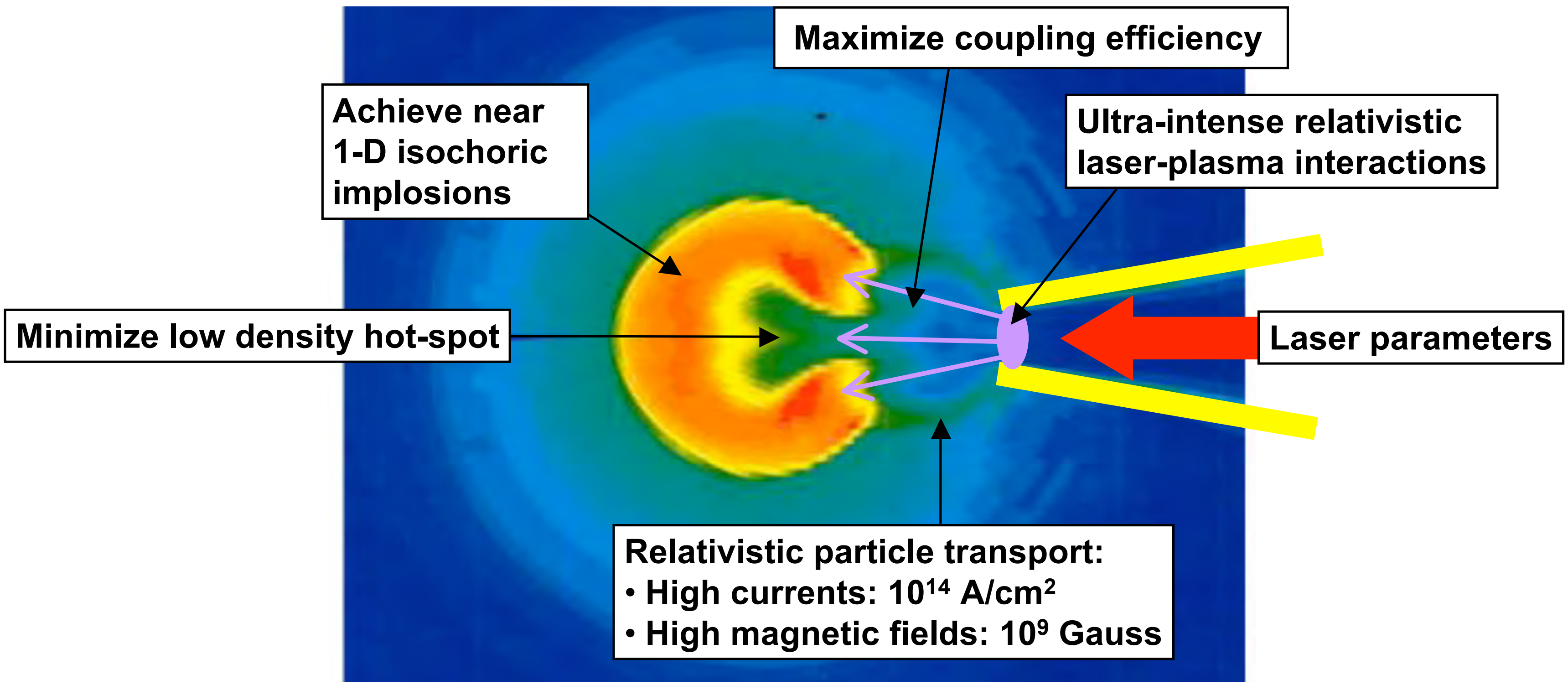

| | |
|---|---|
| Technology | 18.9M |
| Science | 7.7M |
| Targets & Diagnostics | 5.1M |
| Partnerships/People | 0.7M |

In FY2006, LDRD supported 37 projects in HEDS&T totalling $32.5M

# Fast Ignition – Electron & Proton

*There has been a crescendo of effort supported by the Lab in Fast Ignition, culminating in a Strategic Initiative in FI, and an Exploratory Research in the Institutes in Proton FI*

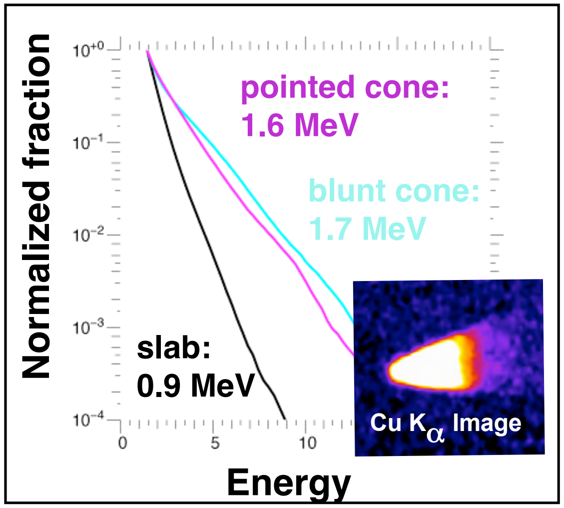
The science of fast ignition is a challenging multi-scale HED physics problem



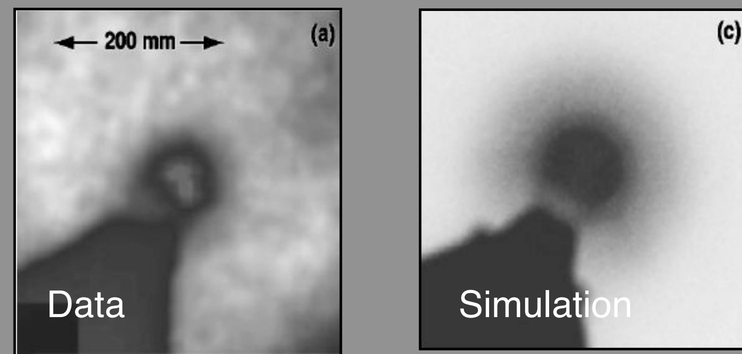
# ("Conventional") Fast Igntion SI (Erik Storm)

*The two main goals of the SI address the physics basis of FI:*

**Laser-electron coupling efficiency**



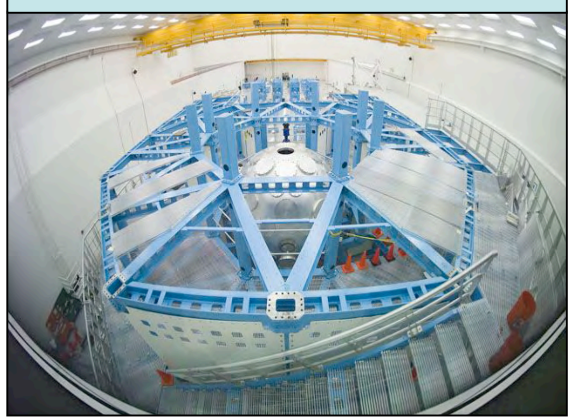

**Test indirect drive hydro point design**



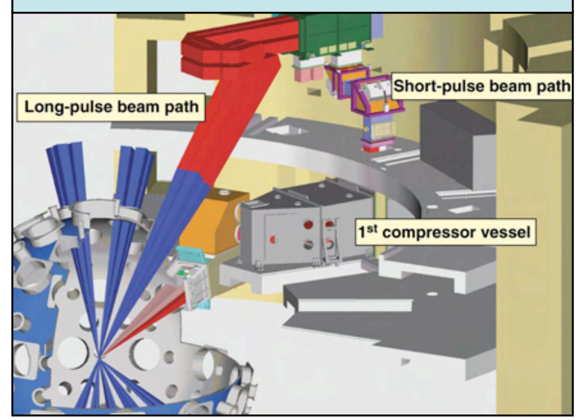

R. B Stephens, S. Hatchett et al., Phys Plasmas 12 056312 (2005)

**Titan**

**OMEGA**



**NIF**

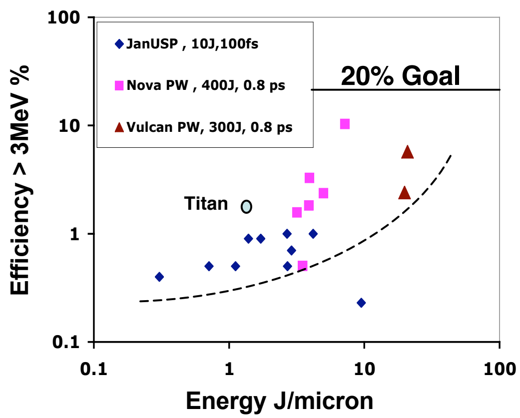



*The SI involves experiments at JLF, Omega, NIF; simulations at BG/L etc.*

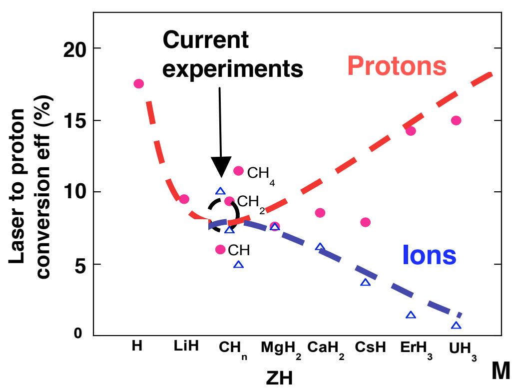
# Proton Fast Ignition (new project; Prav Patel)

*Proton FI offers many potential advantages - less complex transport, better collimation, more efficient energy deposition. The project will focus on PIC & LSP simulations, exploring hydride targets, increasing the proton conversion efficiency to ~20%, and integrated sub-scale proton FI experiments.*

## Proton conversion efficiency



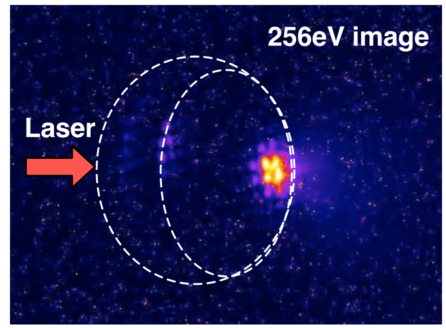

Highest conversion efficiency measured to date ~ 5-10%
Need 20%



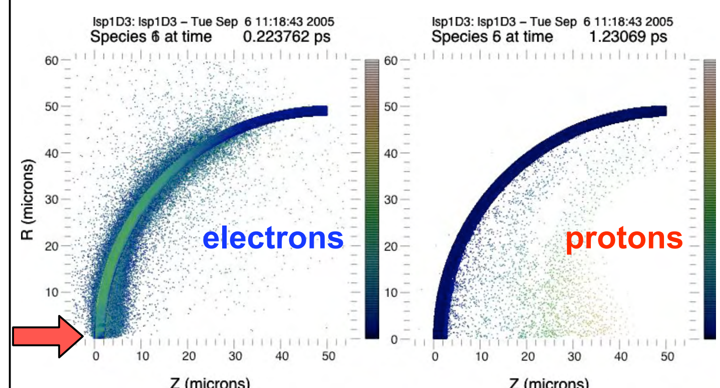

LSP modeling suggests hydride targets can double efficiency

M Foord et al.

## Proton focusing

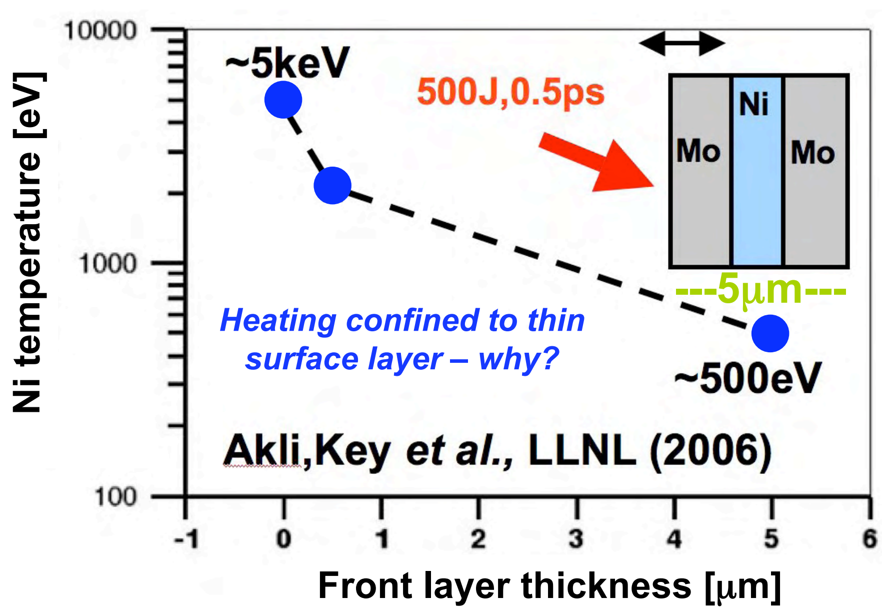



Titan focusing data gives ~30μm spot, and ~100eV temperature
Need 40μm and 10keV




LSP is being applied in 3-D to study the dynamics of proton acceleration and focusing

# Short Pulse Laser Interactions with Matter (Andreas Kemp)



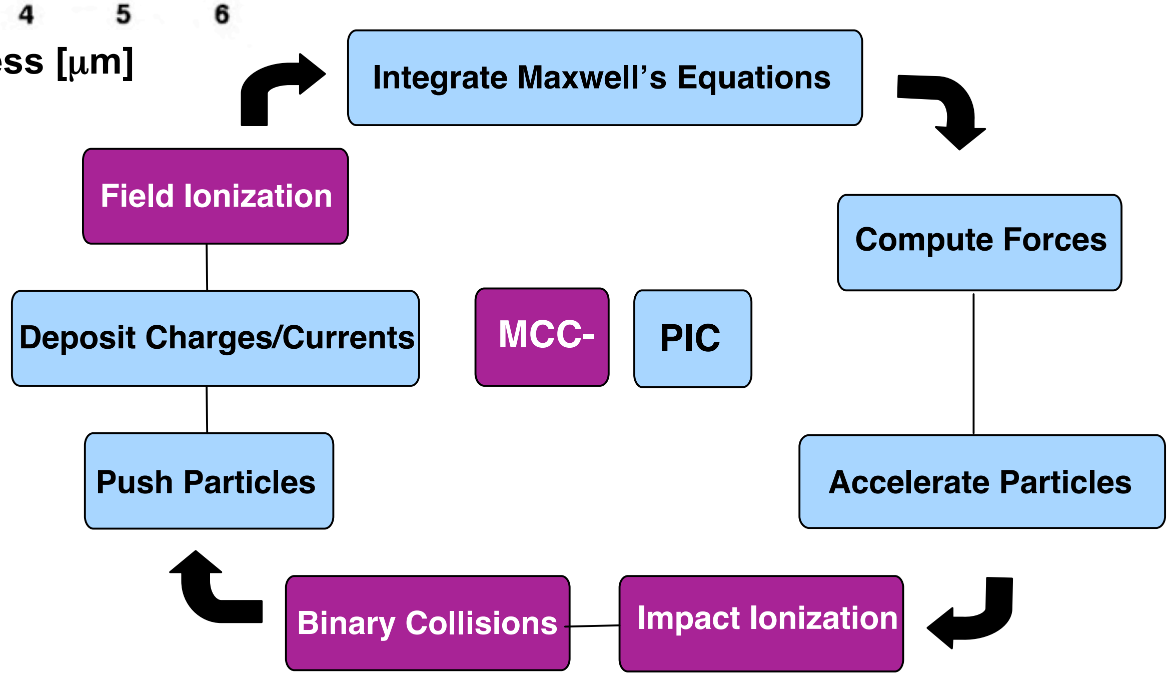

*This project attacks a classic problem in physics - the “Langmuir paradox”, i.e. how are electron energies randomized so quickly in collisionless plasmas?*

Possible heating mechanisms:

– Resistive inhibition
– Surface magnetic fields
– Laser magnetic fields
– Role of pre-plasma
– Runaway electrons?

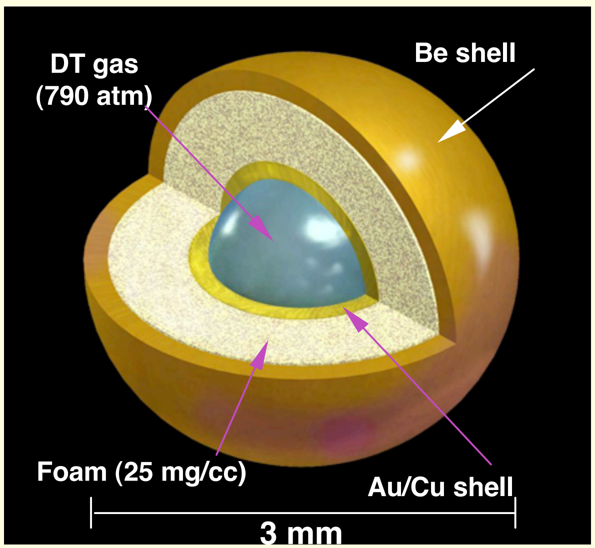
*Project methodology:*

*Couples 3D Particle-in-Cell (PIC) with Monte Carlo Collision (MCC) and ionization operators*



# Nanoscale Target Fabrication S&T – An Enabling Strategic Initiative (I)

*Virtually all of the ICF and Stockpile Science targets need critical materials innovation. This project was driven by a non-cryogenic alternative ignition target design, which while of lower yield, appears robust and offers many advantages. It represented a truly integrated and tight coupling between the physics performance calculations, and the materials development campaign.*




**Double-Shell Prototype Target**

**Advanced, full-density materials**

**Nanoscale, ultra-low-density materials**

**Novel 3D fabrication methodologies**

**Design coordination**

**Assessing trade-offs and options**

**Instability mitigation techniques**

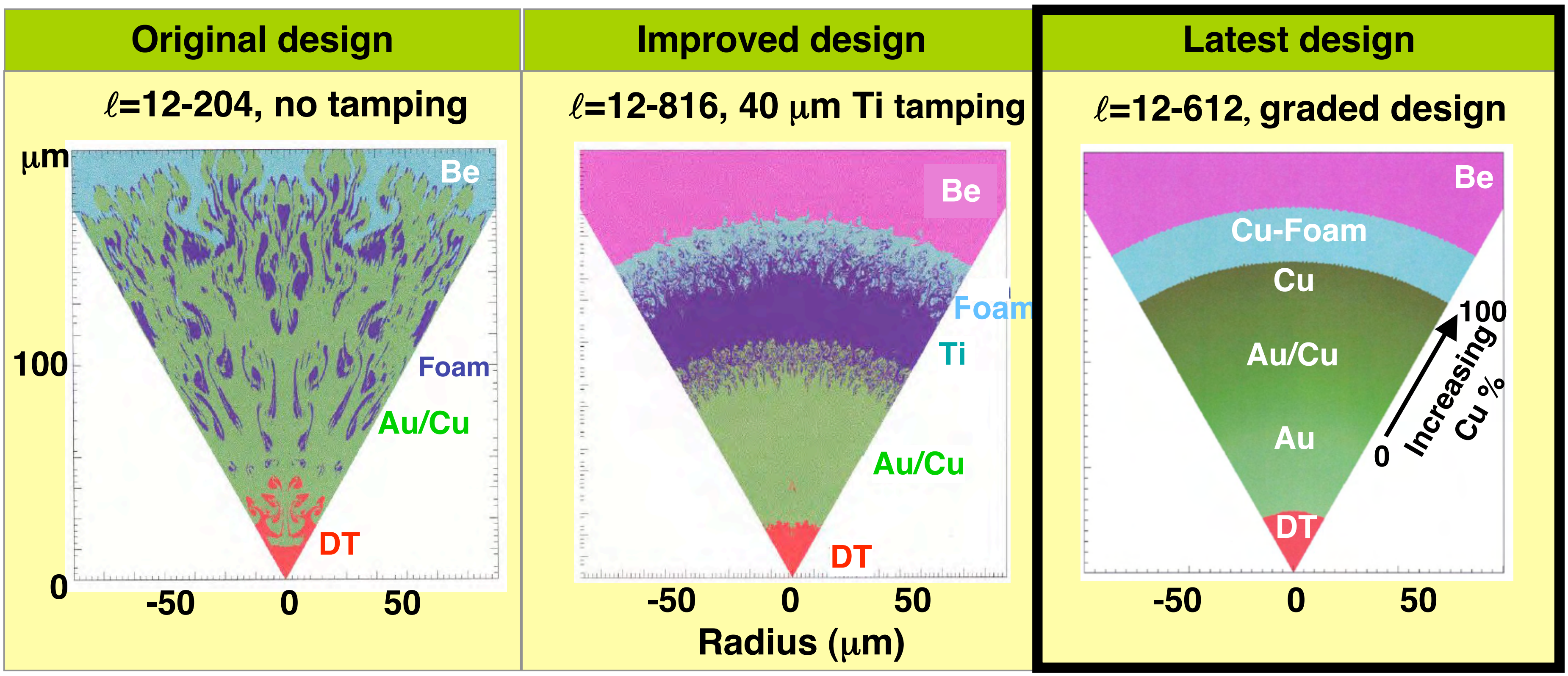
**Target campaign liaison**

(Peter Amendt A/X-DNT & Alex Hamza CMLS)

# Nanoscale Target Fabrication S&T – An Enabling Strategic Initiative (II)

*What is needed to succeed:*

- *Full density and strength ablators - CVD diamond gaining interest as a candidate*
- *Metallic foams of ultralow density (50-100 mg/cc) and nanoporous (<500 nm pore size)*
- *Graded-density bimetallic (Au/Cu) nanocrystalline alloys, of high strength*
- *Tight tolerances on shell concentricity (<5μm), surface smoothness (<50nm), gaps*

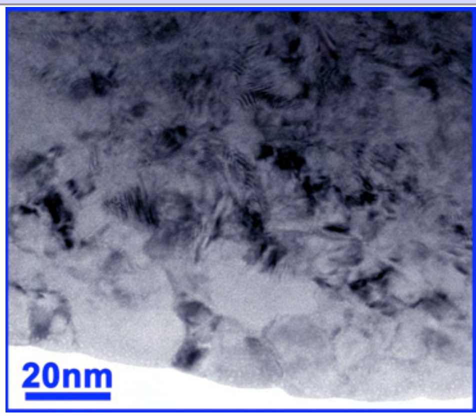



*The payoff is huge – dramatic suppression of hydrodynamic instability growth*

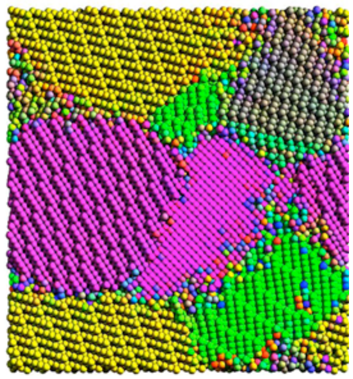
# Nanoscale Target Fabrication S&T – An Enabling Strategic Initiative (III)

*Progress in materials fabrication on all fronts has been outstanding*

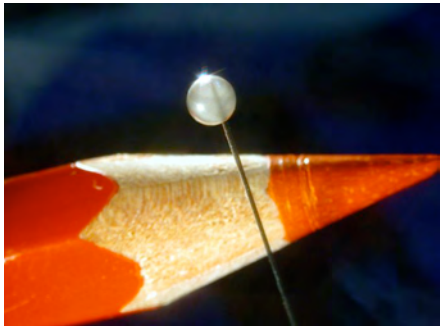
**10x stronger Au/Cu**




**Stable nanoalloy design for permeation**

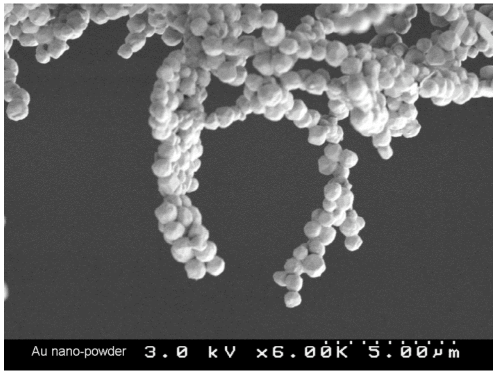


**100 micron CVD Diamond ablator**

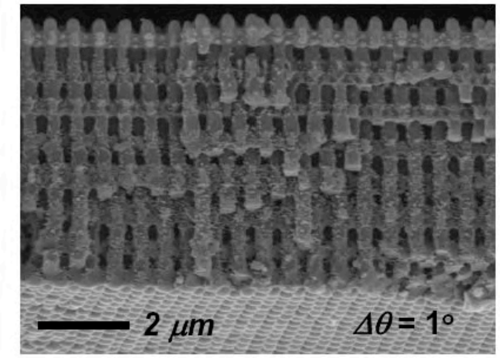


**Lowest density nanoporous metal**


**Ultra-low density metal for hohlraums**

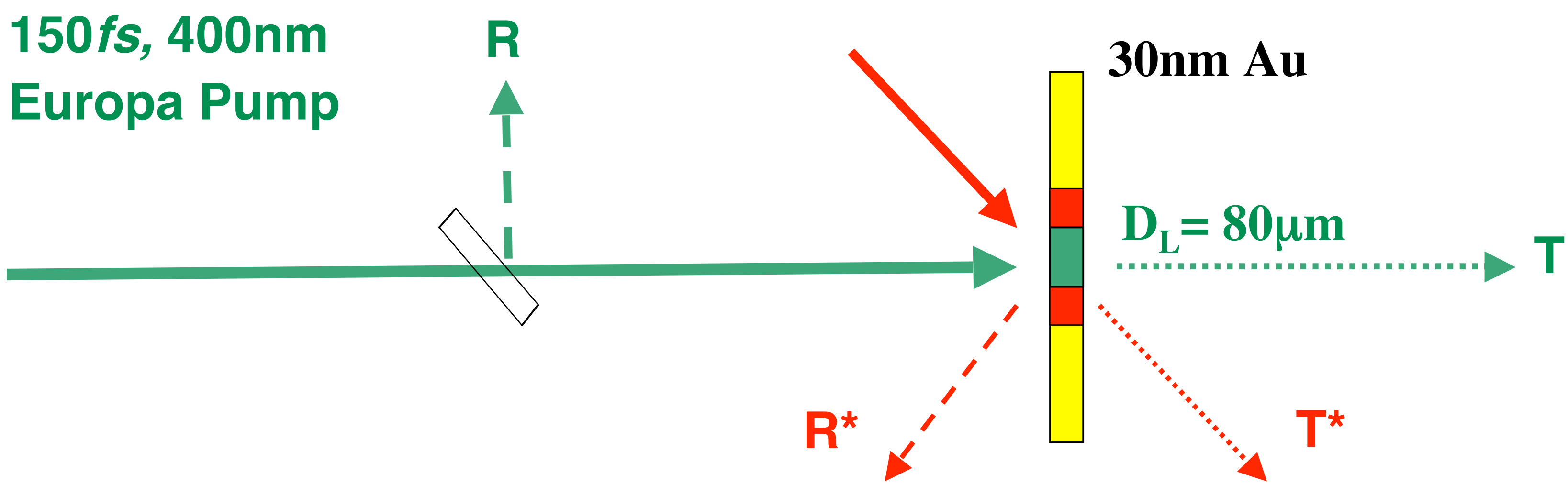


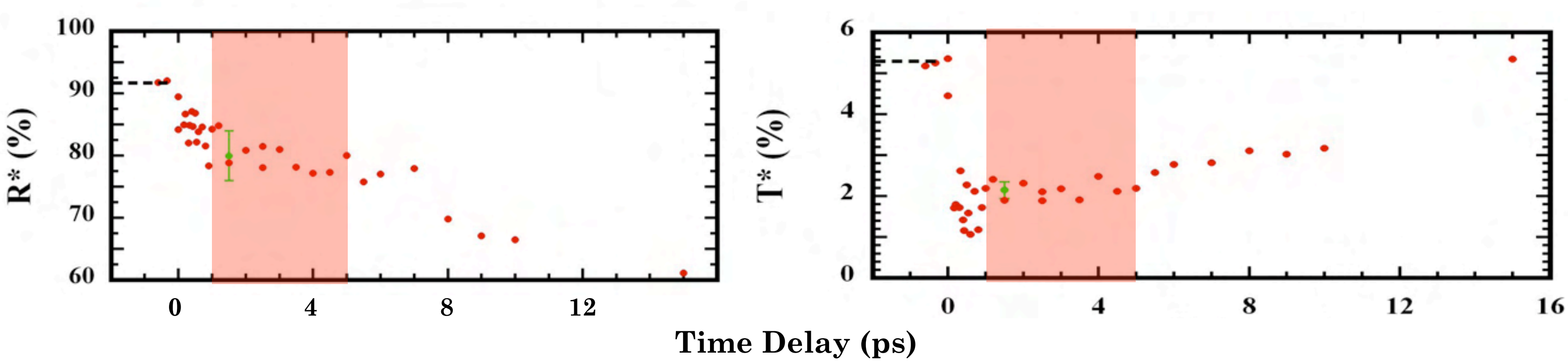

**Density gradient mat'ls for stability**



# Warm Dense Matter Studies with an Idealized Slab Plasma (Andrew Ng)

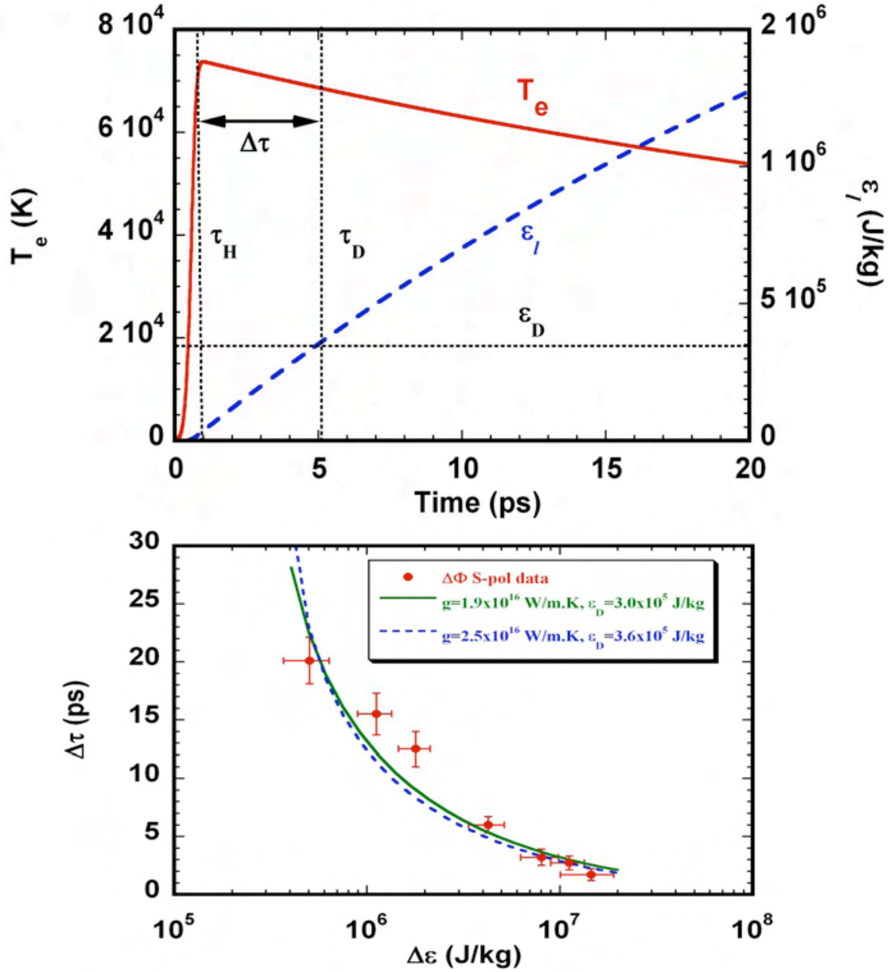
*This project studied electrical conductivities, lattice stability, band structure and electron density of states in Au, by isochoric laser heating at JLF. An interesting quasi-steady state temporal behavior was revealed, and evidence for a superheated solid was found.*



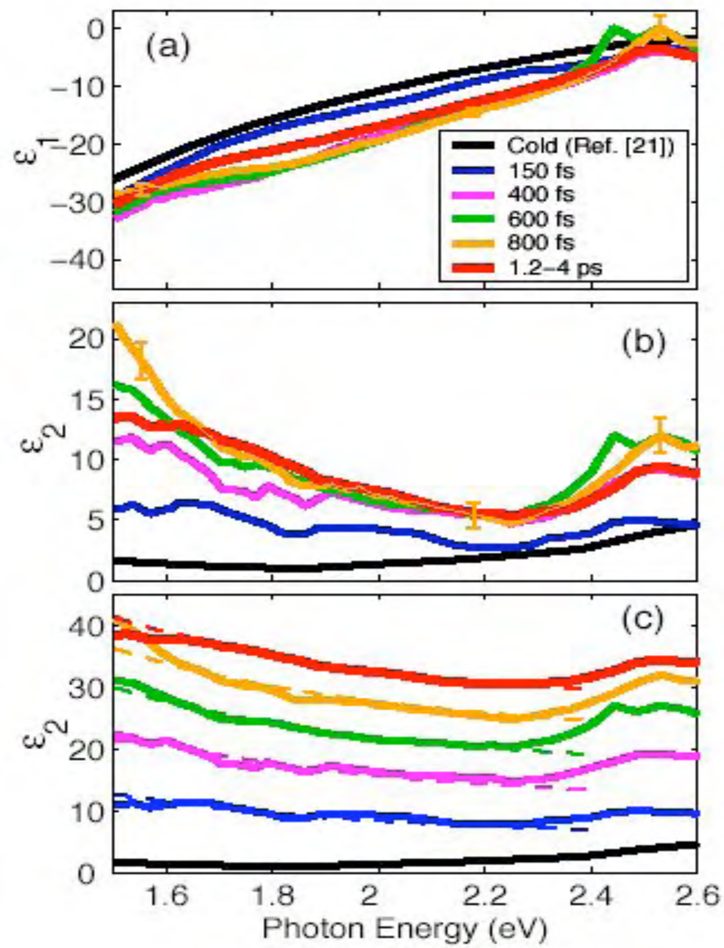



# Warm Dense Matter (II) – Analysis

*Model and fits of disassembly time*



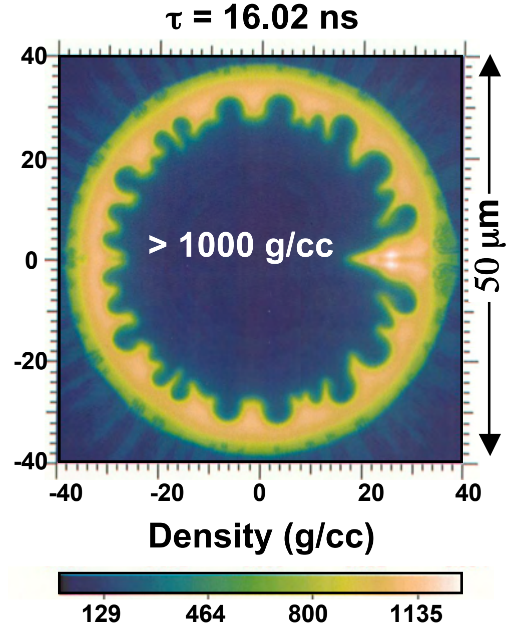

*Measurement of $\varepsilon_{1,2}$ , and evidence for intra- and inter-band transitions*



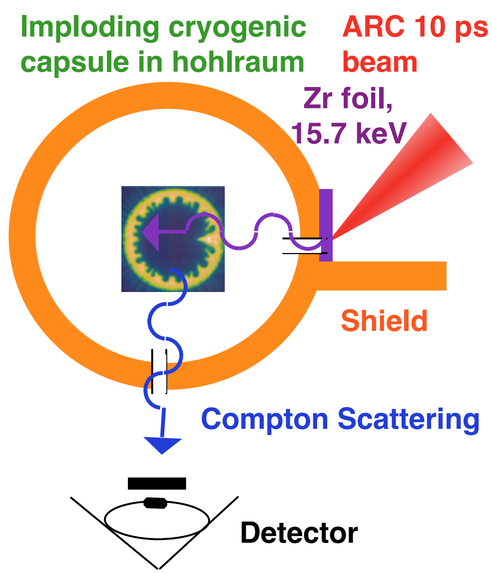

If *d*-band is the result of long range order, this would be first evidence of the quasi-steady state being a superheated solid

# NIF will produce conditions of stellar interiors that will be directly measured with x-ray scattering (Siegfried Glenzer)

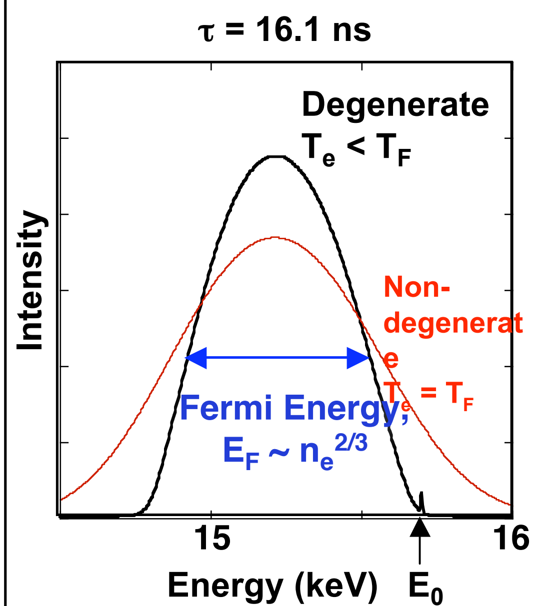
**Radiation-hydrodynamic simulations of NIF implosions**




**Compressed fuel at high density (up to 1000 g/cc), efficient at low $T_e$: $T_e/T_F$<1**




**X-ray scattering spectrum from implosion calculated by post-processing HYDRA**



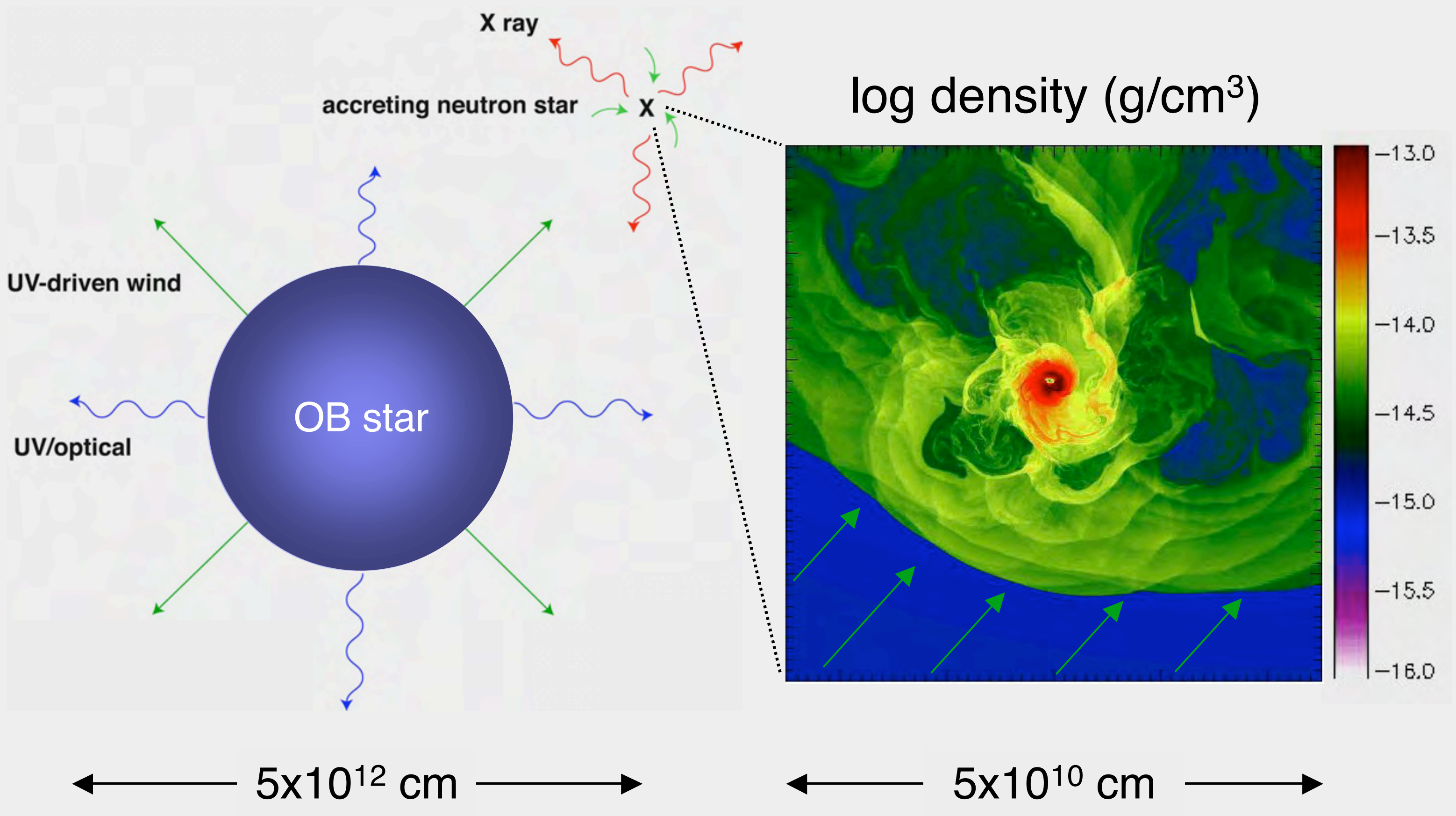

- Goal: Characterize shock-compressed matter with NIF ARC
  - Measure temperature and density with ultrahigh temporal resolution
  - Compressibility, demonstrate $n_e$ measurement of up 1000 g/cc

NIC National Ignition Campaign

University Relations Program

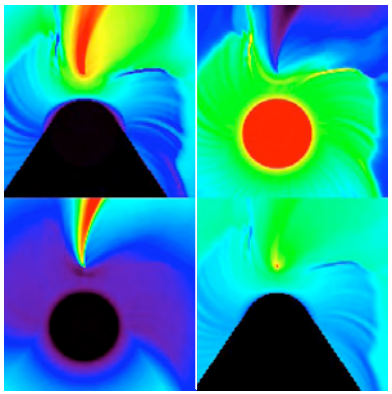
# Hydrodynamic & Spectral Simulations of HMXB Winds (Chris Mauche et al.)

*In this simulation project, Mauche, Liedahl, Akiyama and Plewa developed a model for simulating complex x-ray spectra from HMXB winds.  The project leveraged the NNSA ASC Alliance FLASH code at the University of Chicago.  The team then compare models with Chandra & XMM observations.*



# Hydrodynamic & Spectral Simulations of HMXB Winds – Methodology

FLASH
Hydrodynamic
Simulations



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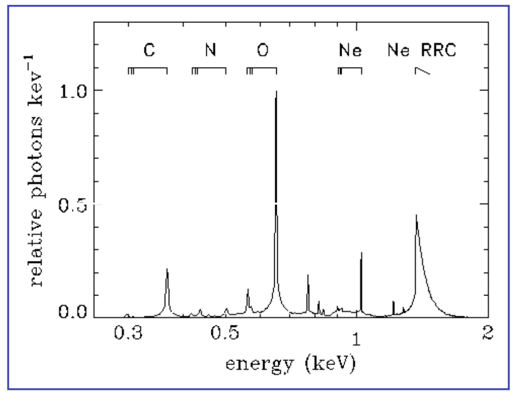
HULLAC Atomic Models
& Monte Carlo
Radiation Transfer

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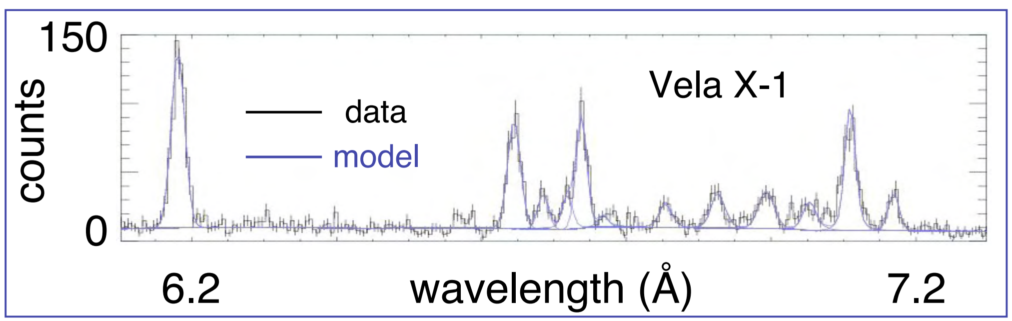
High-Resolution
X-ray Spectra
(*Chandra, XMM*)

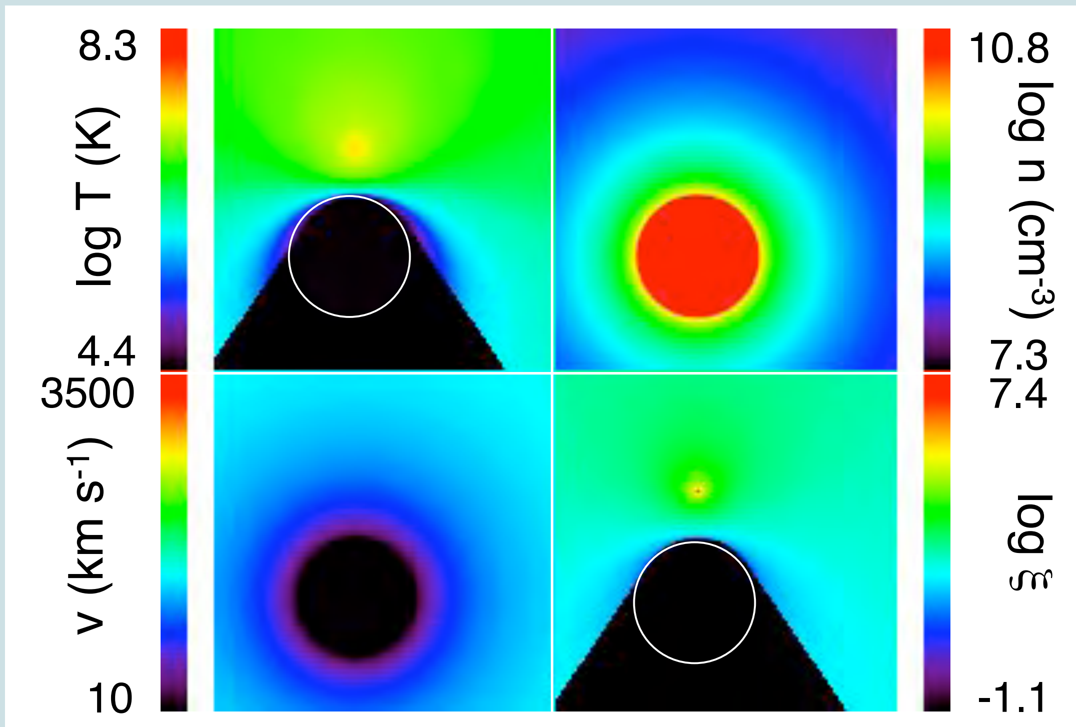
Theoretical spectra

Observed spectra



Hydrodynamic & Spectral Simulations of HMXB Winds – FLASH simulations

## 2-D FLASH simulation of Vela X-1

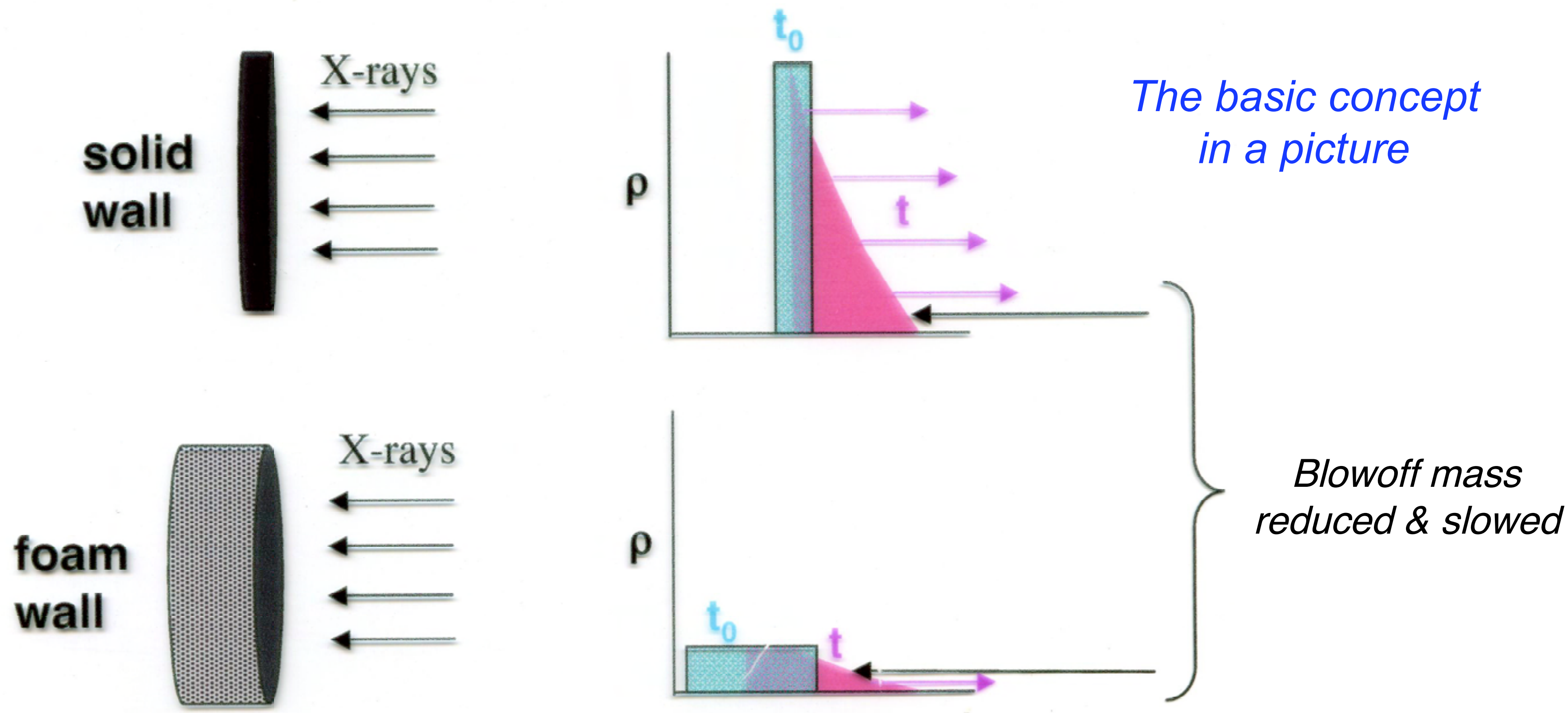



(movie)

# Foam-Walled Hohlraums (Peter Young)

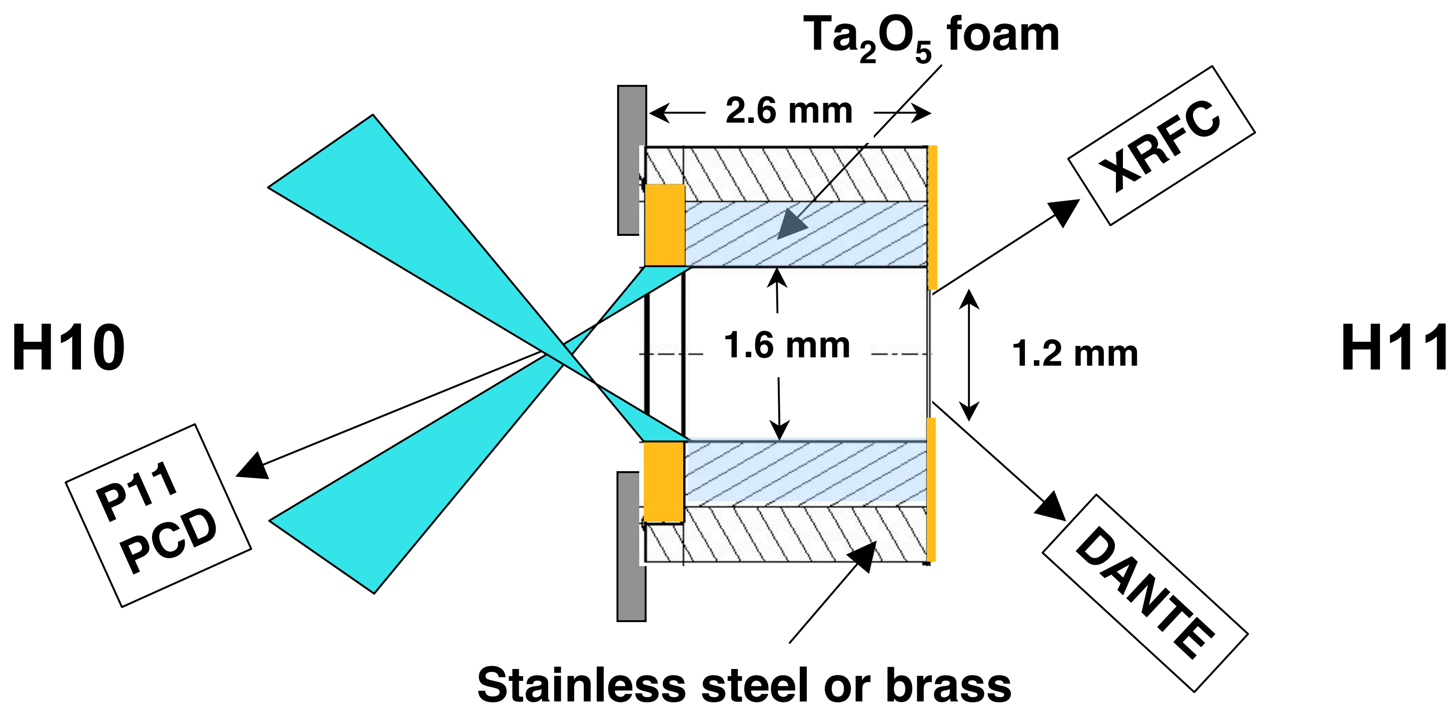
*This project explored the performance of a novel foam-walled hohlraum design. Such hohlraums represent a strategy to increase the x-ray flux in the hohlraum, minimize ablated plasma, and increase performance margins in ICF & HEDS experiments.*

*The basic concept in a picture*



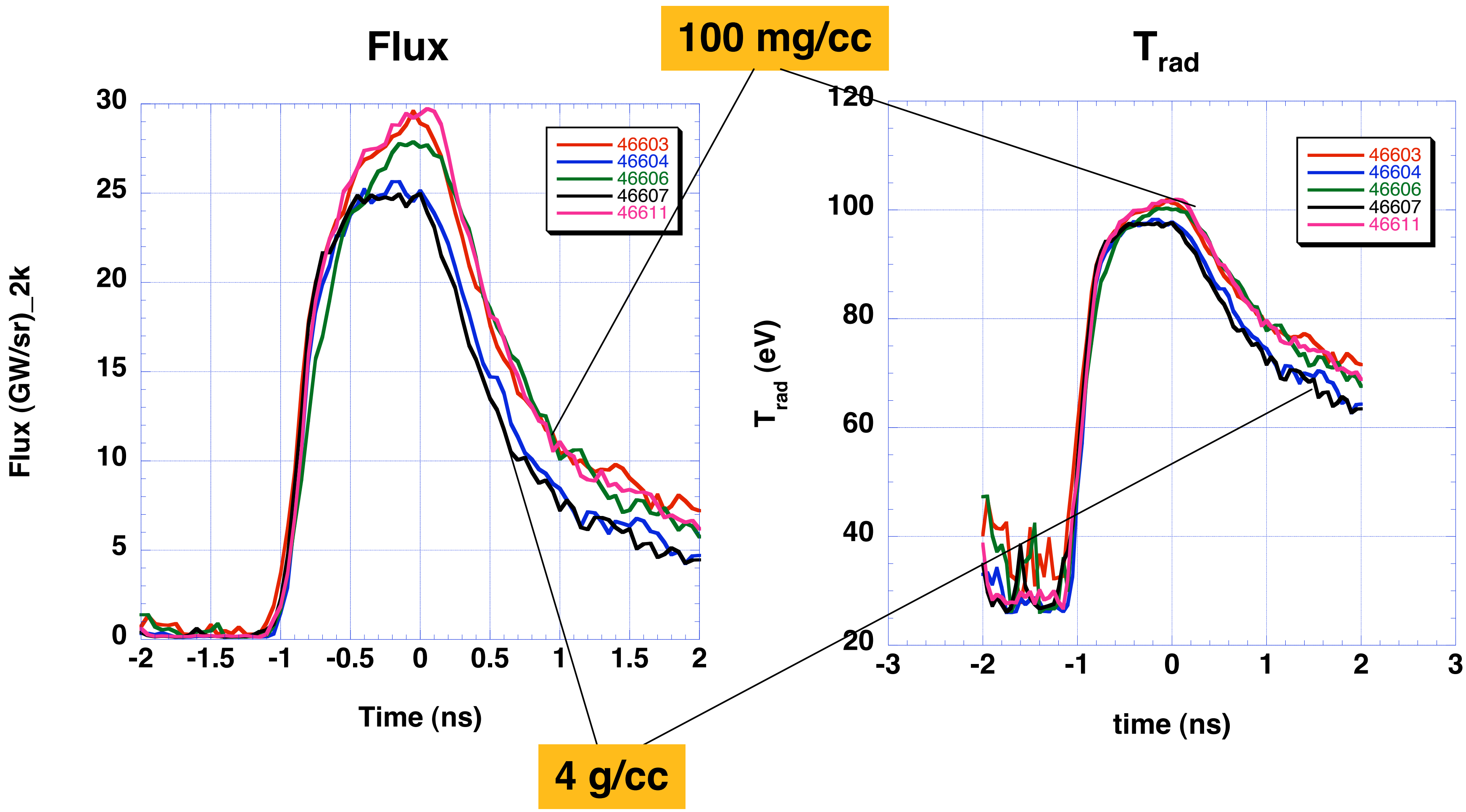
# Foam-Walled Hohlraums – Omega Experiments

*The Omega shots compared x-ray flux from tantalum oxide foam of two densities.*



# Foam-Walled Hohlraums – Results

*The novel hohlraums show significant promise. At peak, the x-ray flux is increased by roughly 15%, and the radiation temperature by 2-3%. The experiments are in good agreement with the modeling.*



# HEDS&T at Livermore – Summary and Conclusions

*HEDS is a prime example of the best science being highly mission-driven*

*The Lab invests in the overall enterprise – we take the 50-year view*

*Note the technology development itself is also high-visibility science!*

*What you have seen is but a small fraction of the overall HED program here*

*As HEDS is just emerging as a formally recognized discipline by the agencies, LDRD and other discretionary resources are extremely important*

*We do most of this work in partnership with other labs, universities, and foreign institutions – we rely a lot on the academics, students & postdocs involved*

*NIF will catalyze a renaissance at the Lab & this will be the growth area. Join us! Encourage your students to come here & think about coming yourself.*

This is an exciting time in the establishment of a new discipline, and HEDS benefits from cross-fertilization from radically different fields – new people, new scientific viewpoints, new techniques!